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CFD Simulations of the MEXICO Wind Tunnel and Wind Turbine

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Abstract

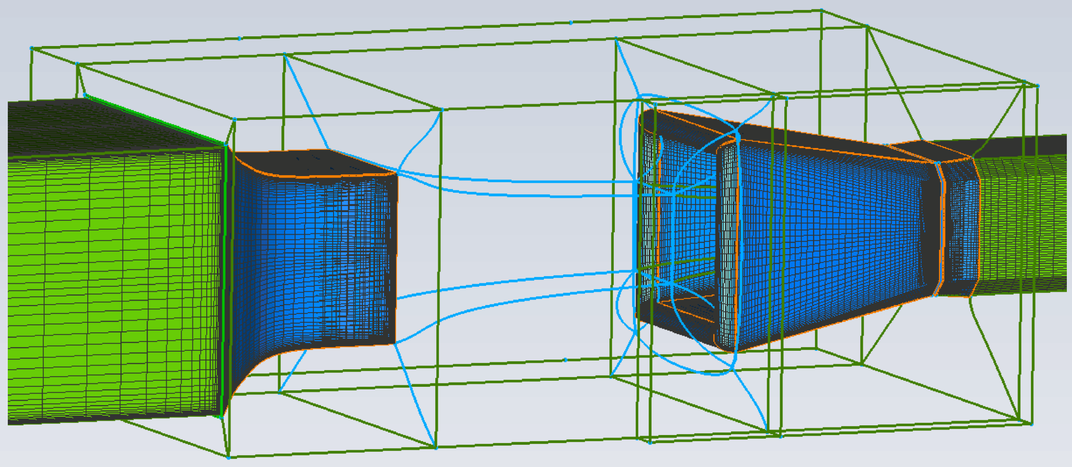
The MEXICO Experiment [1] is reproduced in CFD, including the geometry of the wind tunnel and the wind turbine rotor. The wind turbine is modelled both as a full rotor and as an actuator disc. Various questions regarding the wind tunnel effects on the measurements are investigated.
As in a previous work carried out without modelling the wind tunnel, the CFD methods are found to give satisfying agreement with the axial velocity deficit in the wake. However, confirming the previous work, the blade loadings estimated from CFD are found to be consistently larger than the one estimated from measurements. In order to investigate further this issue, the loadings estimated from measurement are used with an actuator disc (AD) model. This approach gives a too small wake deficit in comparison with the measurements, which tends to agree with the full rotor (FR) computation results.

Method

The flow solver used in this work, EllipSys, is an in-house general purpose CFD code developed at Risø DTU [2] and DTU MEK [3]. The Reynolds stresses are estimated, in this work, using a k-ω-SST model [4].

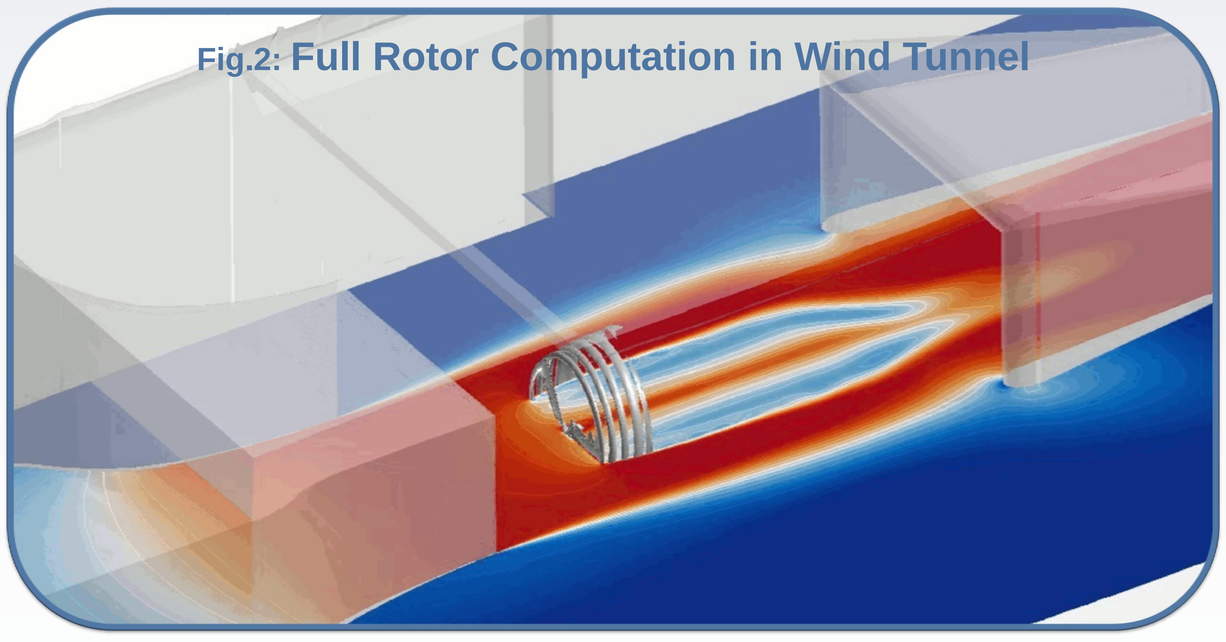
The wind tunnel is meshed using the software Pointwise as $386\ 32^3$-cell structured blocks. The slots´(hole) at the collector exit are taken into account. The support structure of the wind turbine rotor and the support structure of the collector are not considered in this study (Fig.1). The inlet and outlet of the domain have been extended, and the cells size gradually spreaded out. The wall boundary conditions are taken as slip condition (symmetry). Having a mesh fine enough to simulate the boundary layer in a realistic fashion would have been too computationally expensive and would have taken a significantly longer time to mesh. The shortcoming of this approach is that there will not be any development of a boundary layer on the walls of the room, nozzle and collector. The assumption made is therefore that this boundary layer does not influence significantly the region of the flow where the measurements are made.

Fig.1: Wind Tunnel Mesh



Two wind turbine models are used.
• An actuator disc model [5] with prescribed axial and tangential forces estimated from the MEXICO measurements (see Fig.3).
• A full rotor computation [6] (Fig.2) based on the complete geometry of the MEXICO rotor (excluding the spinner, the hub and the tower). Three overset meshes are used in addition to the wind tunnel mesh to smoothly interpolate from the very fine rotor mesh to the coarser wind tunnel mesh.

Fig.2: Full Rotor Computation in Wind Tunnel



Results

Fig.3 describes the different wind turbine blade loadings. The Actuator Disc (AD) loadings are splined from the measurements points, while the Full Rotor (FR) computations loadings are estimated from the simulation results.

Fig.3: Wind Turbine Loding Along Radius
Actuator Disc (AD) vs Full Rotor (FR)

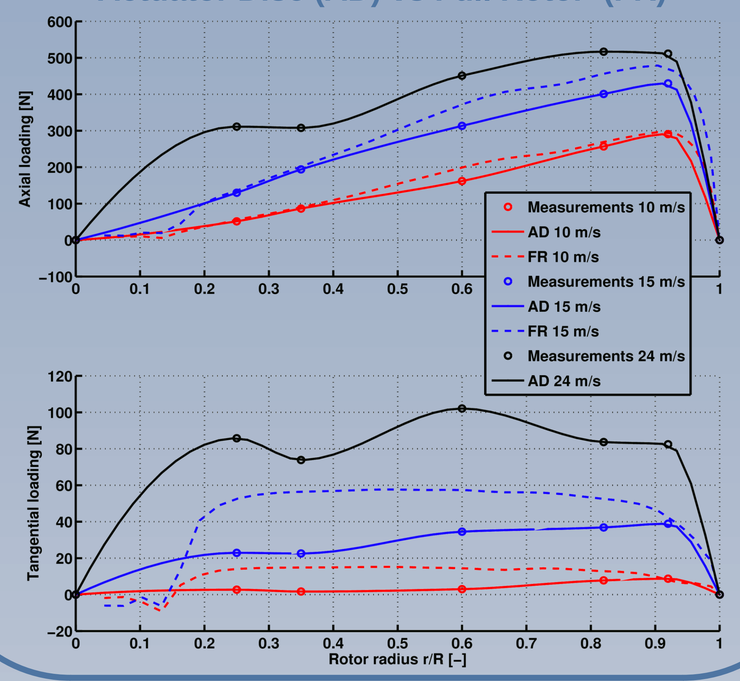
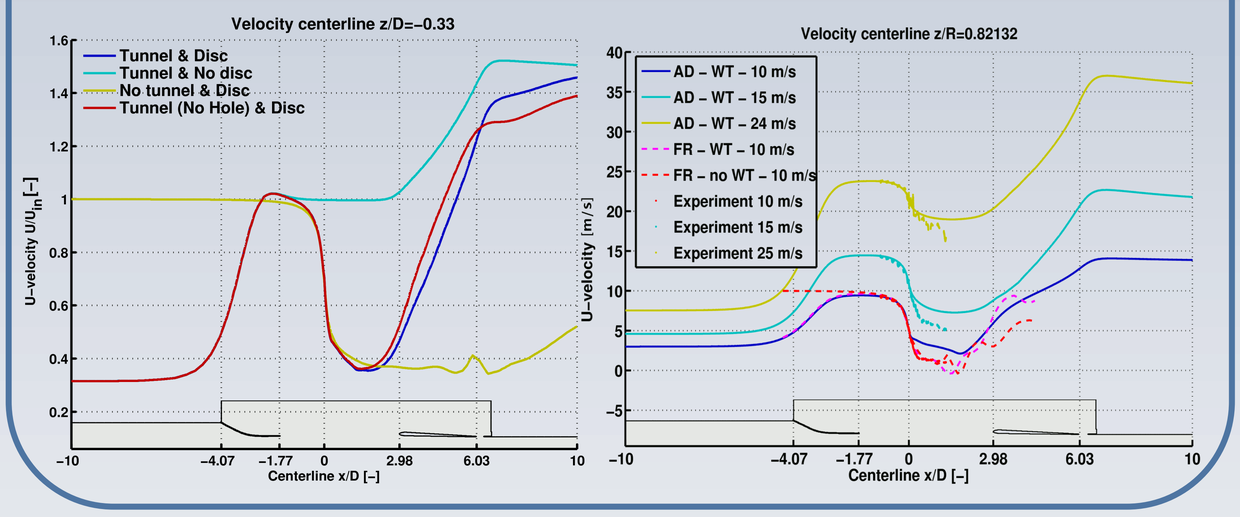


Fig.4a presents a comparison between the axial velocity in an horizontal line passing through the wind tunnel at hub height and z/D = 0.33 of different steady state actuator disc runs. Fig.4b shows the axial velocity in an horizontal line passing through the wind tunnel at hub height and z/D = 0.82 for the different wind turbine models, with and without the wind tunnel, for different inlet wind speed and compare them with the relevant wind speed measurements.

Fig.4: Axial Velocity Along Centerline
Actuator Disc (AD), Wind Tunnel (WT) and Full Rotor (FR)



The flow characteristics found with the actuator disc model, based on the forces from the measurements, do not give satisfying results in comparison with the measurements (Fig.4b). They systematically under predict the wake deficit in comparison with both the measurements and the full rotor computations. This seems to indicate that the loadings estimated from the pressure sensors are not large enough to obtain the measured velocity deficits. The full rotor computation give a closer match to the velocity measurements, they obtain significantly higher loadings (Fig.3).

Conclusions

• The CFD simulations, irrespectively of the method used, cannot seem to agree on both the velocity and loading measurements at the same time.

• There seems to be a mismatch inbetween the loadings measurements and the velocity measurements.

• The tunnel effects (including the slots) do not seem to affect significantly the simulations, in the area of interest and do not explain this mismatch.

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